NOPP: Circulation, Cross-Shelf Exchange, Sea Ice, and Marine Mammal Habitats on the Alaska Beaufort Sea Shelf

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LONG-TERM GOALS

Our long-term goals are to understand how the physical oceanography, sea-ice dynamics, and marine mammal utilization of arctic shelves will change in response to a diminishing ice cover. We thus seek to understand better the wind-forced response of the shelf and shelfbreak and the cross-shelf exchange of mass, materials, and momentum. These responses will likely affect the use of arctic shelves by marine mammals. We are applying several recently developed technologies to an arctic shelf in synergistic ways, including passive acoustic recorders, moored profiling CTDs, autonomous underwater vehicles, shore-based current mapping radars, and geophysical processing tools to determine ice displacement and deformation. These bear on another long-term goal which is to demonstrate the applicability of these technologies to other arctic shelves.

OBJECTIVES

Predicting how arctic shelves will adjust to changes in ice conditions requires that we address several critical unknowns pertinent to the present-day functioning of arctic shelves. These unknowns motivate our specific proposal objectives, which are to determine:

1. The annual cycle of shelf circulation and stratification,
2. How circulation and stratification change across the shelf due to variations in sea-ice distribution, river runoff, and winds,
3. The seasonal and synoptic variations in the exchange of mass, momentum, and water properties across the shelf, and
4. How marine mammal occurrence on the shelf and slope varies in response to seasonal and synoptic changes in winds and ice-cover.

APPROACH AND WORK PLAN

To attain these objectives we will conduct in-situ measurements and retrospective analyses of historical data, which, in aggregate, encompass a broad range of space and time scales. The observational components and the investigators primarily responsible for each of these are:

1. a cross-shelf array of moorings and the occupation of CTD sections (Pickart and Weingartner);
2. high resolution hydrographic/velocity surveys from the REMUS, an autonomous underwater vehicle (AUV) (Plueddemann);
3. high-frequency (HF) surface current mapping radars (Weingartner);
4. autonomous acoustic recorders for marine mammal vocalizations (Moore and Stafford); and
5. satellite-derived estimates of sea ice concentration, displacement, deformation, and characteristics of the sea surface (Holt and Kwok).

Field work began in August 2008 and consisted of the deployment of moorings, the occupation of CTD sections, and REMUS surveys. The moorings (including the acoustic recorders) were in place for a complete annual cycle and were recovered in August 2009, when additional CTD and REMUS surveys took place. Winter and spring 2009 activities also included satellite data collection and analyses, processing AUV and CTD data sets from summer 2008, preparation for the 2009 field effort work, and retrospective analysis of historical physical oceanographic data from the Alaskan Beaufort Sea (ABS) shelf. The field program took place on the central ABS shelf, offshore of the Colville River, and was centered on the cross-shelf oceanographic mooring array (Figure 1).

WORK COMPLETED

From August 5 – 16, 2008, we successfully deployed 17 moorings (Figure 1), occupied 3 CTD transects, and several AUV transects (Figure 1). The moorings were from three separate programs: two funded under the auspices of NOPP (one being this project and the second the "Episodic Upwelling of Zooplankton within a Bowhead Whale Feeding Area near Barrow, AK" led by Dr. Carin Ashjian of Woods Hole Oceanographic Institution) and a third the ONR-supported Ice Covered Response to Atmospheric Storms (ICORTAS) project led by Dr. Harper Simmons of the University of Alaska.

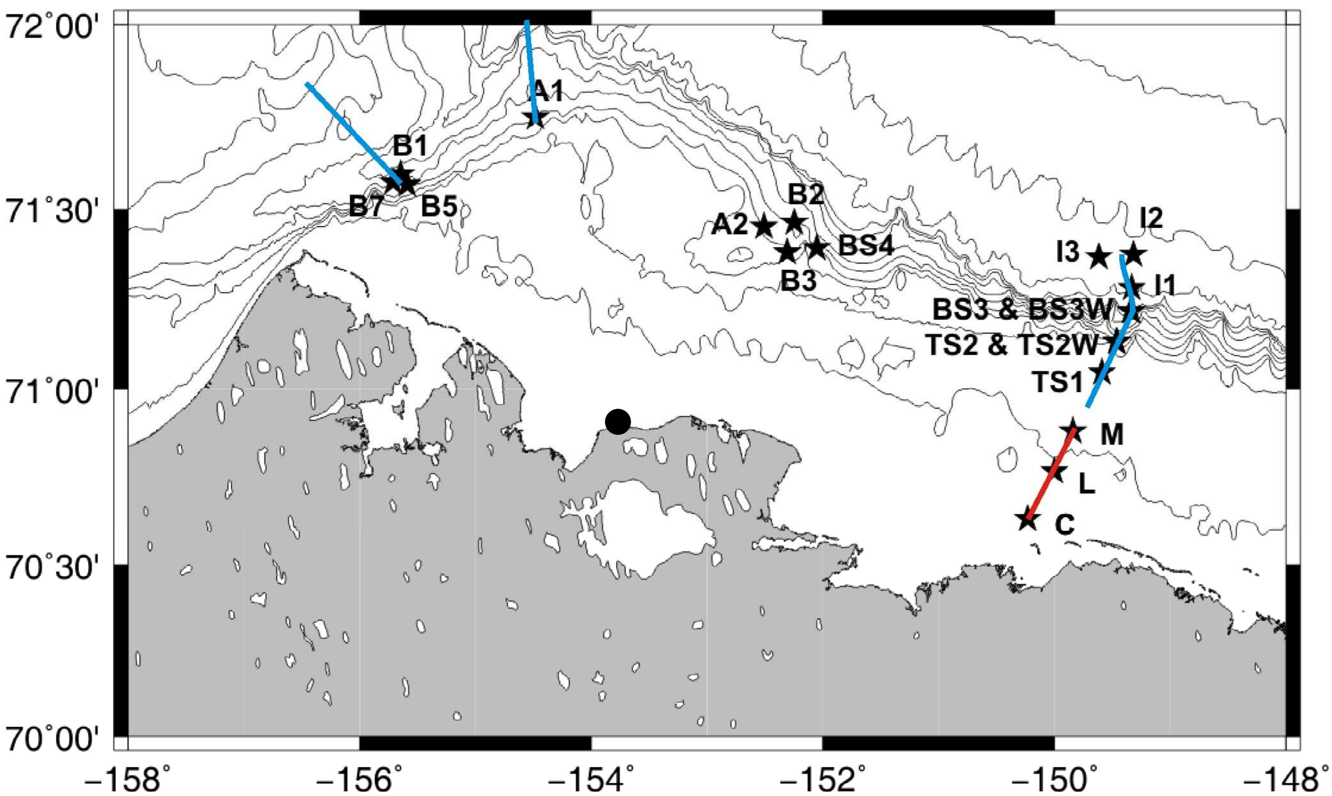

Figure 1. Location of current meter and/or passive acoustic (marine mammal) recorders moorings deployed in August 2008 from the USCG icebreaker Healy and the R/V Annika Marie. The red line shows one of the AUV transects on the inner shelf and the blue lines are CTD transects. The black circle shows the approximate study location of Dr. Cameron Wobus's NOPP project addressing coastal erosion.

Moorings C, L, and M were deployed on the 13, 19, and 28 m isobaths on the inner-shelf from the *R/V Annika Marie*. Each of these moorings had an ADCP and a temperature-conductivity-pressure recorder with all instruments within 1 m of the seabed to avoid damage from deep ice keels.

Moorings TS1 and TS2 were on the 35 and 45 m isobaths, and moorings BS3 and BS4 were deployed near the shelfbreakon about the 140 m isobath.. Each of these contained an Arctic Winch, which profiles from the bottom or 50 m depth (whichever is deeper) to the surface once a day. Moorings BS3 and BS4 also include moored profilers to capture the vertical T/S structure between the bottom and 50 m depth. The ICORTAS array was deployed on the 1265, 1865, and 1665 m isobaths. In aggregate, the cross-shelf and slope array provided an unprecedented data set for examining arctic shelf processes from the nearshore (land fast ice zone) to the deep slope (pack ice). Mooring BS4 was deployed at the shelfbreak along 152°W, west of the main mooring line. This site was previously occupied by Pickart's moorings from 2002 – 2005. Mooring BS4 adds to that time series and provides a temporal context for interpreting the results from our NOPP array. The cross-shelf array also included whale recorders (moorings TS2W and BS3W), to enable interpretation of marine mammal recordings in conjunction with the physical oceanographic data.

The other moorings in Figure 1 were part of Ashjian's program and consist of marine mammal recorders (B1, B2, B3, B5, and B7) and marine mammal recorders in combination with current meters (A1 and A2). The complete mooring array provides good along-stream/shelf coverage of the circulation, water properties, and marine mammal calls over a distance of 200 km and cross-shelf coverage over a distance of 100 km. In addition, the two sets of marine mammal recorder triads (B1, B7, B5 and B2, B3, and A2) were to permit estimates of source levels of whale calls and an index of the number of animals calling at any one time.

Mooring recoveries, ~ 10 AUV sections on the inner shelf, and CTD surveys were completed in August 2009 aboard the USCGC *Healy* and the charter vessel *Annika Marie*. The *Healy* 2009 CTD sections are shown in Figure 2, which also shows the deployed locations of an NSF-funded AON current meter mooring and an MMS-funded meteorological buoy that were deployed on the NOPP recovery cruise. The planned HF radar installation in 2008 had to be cancelled because a large drill rig was placed near one of the planned radar sites in July. This obstruction, along with planned oil field construction activities, risked damage to our installation and/or a time-varying RF environment that we could not control or measure. There was insufficient time to find another site and acquire the requisite permits for an alternate site by the time we learned of this development. We instead deployed an HF radar installation in Barrow and Wainwright, Alaska, in fall 2009, with this installation supplemented by funding from the MMS, Shell Exploration, and ConocoPhillips.

RESULTS

Although we recovered most of the moorings deployed in this project there were several problems. One of the whale recorders (BS3W) was apparently moved off site and could not be recovered. Recorder TS2W did not release but was recovered by dragging. In addition, the inshore mooring C (on the 19-m isobath) was destroyed by sea ice. Although communications with the release were successful, and triangulation provided a precise location, the mooring could not be found. Divers attempted to find the mooring, but only succeeded in recovering a small part of the mooring frame. They observed that the mooring site was heavily ice-scoured with scour channels exceeding 2 m depth. Apparently the mooring was shattered by sea ice and its various parts buried under sediment. The divers spent nearly 8 hours on the bottom attempting to find the mooring. Two of the Arctic Winches were also missing and we conclude that these were removed by drifting ice during the winter of 2009While data analyses are under way. In spite of these various drawbacks, we still have an excellent (and unprecedented) data set for this region.

For example the 2009 *Healy* CTD survey revealed a remarkably varying hydrographic structure of the boundary current over the 300 km distance sampled (Figure 3). During the course of a given year there are generally three types of Pacific Water that are advected by the boundary current: Alaskan Coastal

Water (typically between 0◦C and 7◦C), Chukchi SummerWater (typically between -1◦C and 1◦C), and Pacific Winter Water (typically between -1.8◦C and -1.6◦C). These different water masses appear seasonally, with some occasional overlap. However, the survey conducted on this cruise indicates that all three water masses can be found within a short segment of the boundary current, with very abrupt transitions between the different states. As seen Figure 3, Chukchi Summer Water dominated the boundary current in the eastern part of the domain (lines 6 and 7), while the cold and dense Pacific Winter Water was found farther upstream, from 154.8^{o}W (line 3) into Barrow Canyon (lines 1 and 4). Finally, during the re-occupation of the section at the head of Barrow Canyon (line 9), Alaskan Coastal Water was present on the eastern side of the canyon. This complex interplay of water masses (and the concomitant changes in dynamical structure of the flow) indicates that the current is even more variable than previously thought. It is important to sort out the various factors at work in contributing to this variability, and what the ramifications are for issues like shelf-basin exchange and ventilation of the interior basin. The present data set provides valuable information towards a more thorough investigation of such issues.

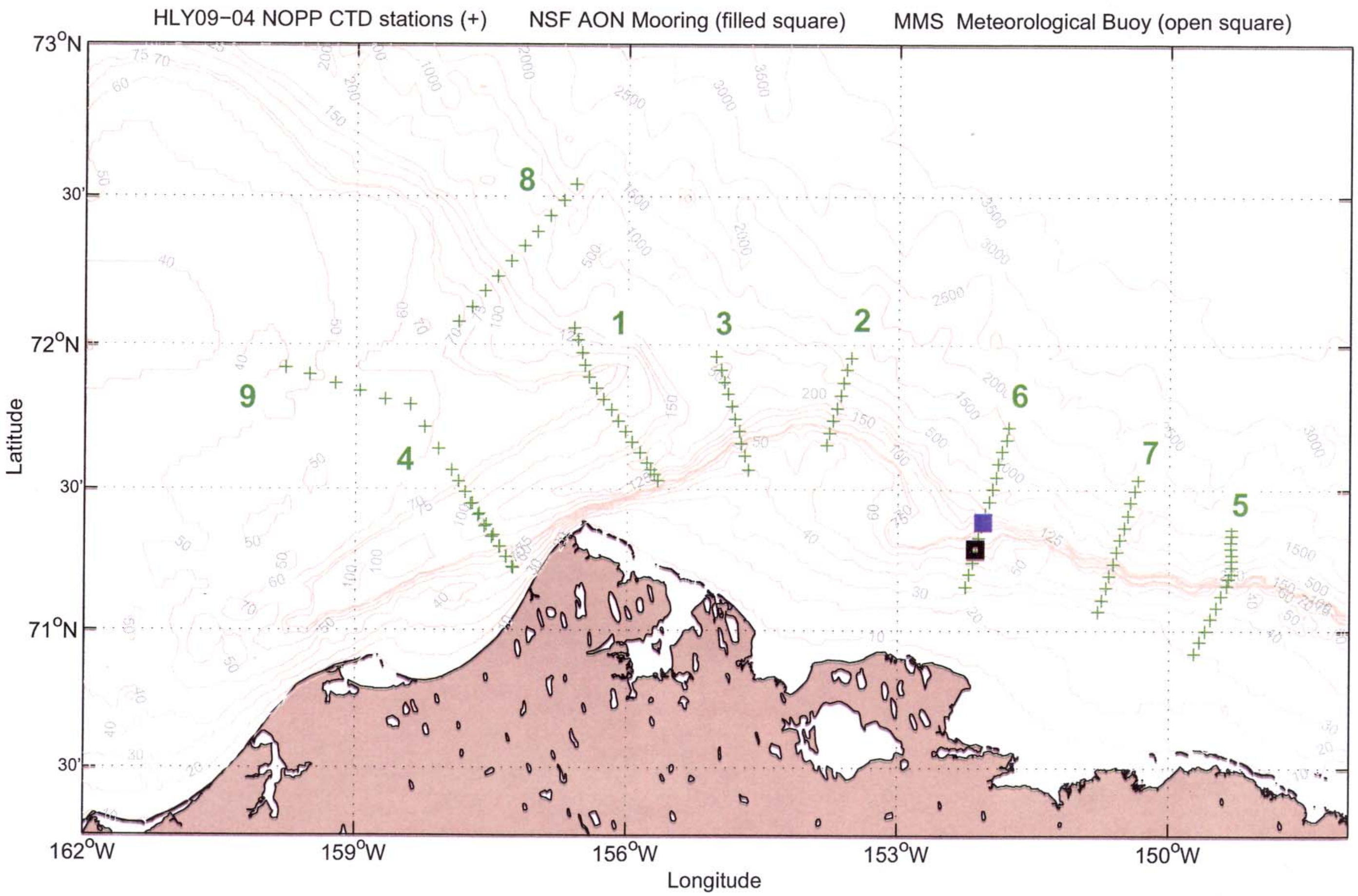

Figure 2: Locations of the CTD sections occupied during HLY09-04 (green +'s). The filled blue square denotes the AON mooring, and the open black square shows the meteorological buoy.

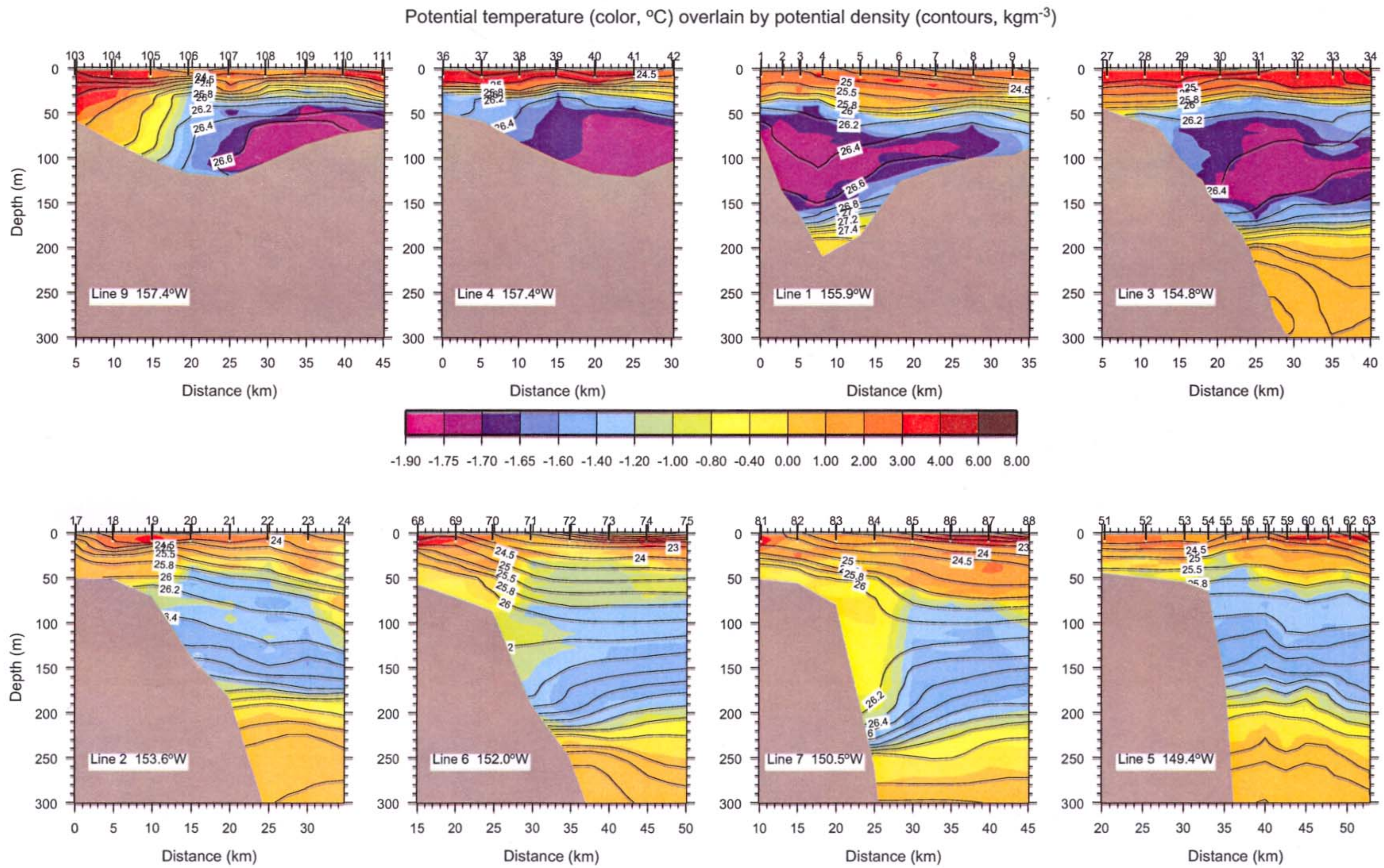

Figure 3. CTD sections occupied during HLY09-04. Station numbers are marked along the top axis. The viewer is looking to the west.

Preliminary examination of the acoustic data from acoustic recorder TS-2 showed that the instrument worked well and recorded bowhead (Figure 4) and beluga whales and bearded seals (Figure 5) in May 2009. The seasonal occurrence of these species will be determined during our analyses. We also found that ambient noise levels at low frequencies are ~10 dB lower in spring than in fall and there were seemingly fewer "loud" events in spring. It also appears that the highest ambient noise levels at low frequencies occur in late fall and early winter with relatively low values at this end of the spectrum in late winter and spring. Higher frequency contributions to ambient noise are in the spring months when bearded seals and bowhead whales are singing and ice noise increases. Preliminary comparison of the data collected this past year shows that there is tremendous intra-annual variability in the acoustic spectra.

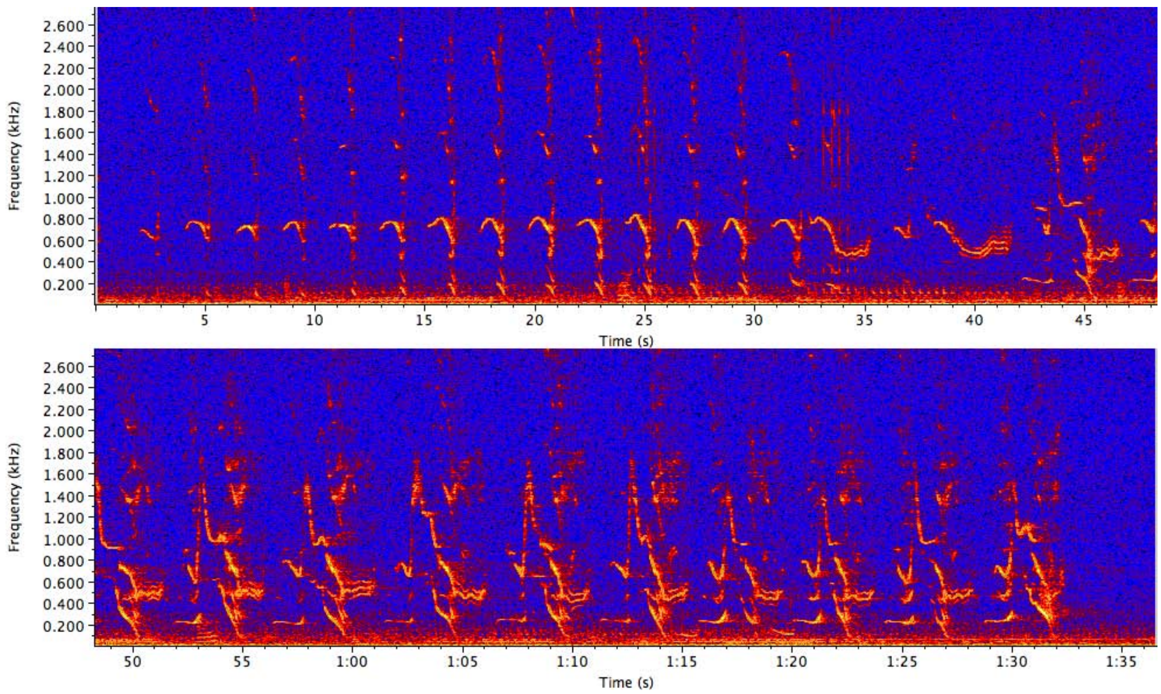

Figure 4. Example of a single spring 2009 bowhead whale song.

Our analyses this winter will include if and how variations in marine mammal vocalizations correspond to variations in circulation, water mass properties, and ice conditions.

We have also collected an extensive time series of deformation fields (derived from SAR) and a time series of AVHRR imagery from the Alaskan Beaufort Sea Shelf. These data are revealing some of the complexities associated with the shelf sea ice fields. For example the image in Figure 6 was taken on January 14, 2009 and it shows a relatively compact shelf ice cover in both the along- and cross-shelf directions, with a relatively narrow shear zone separating the landfast ice from the pack ice. In contrast the March 4, 2009 image (Figure 7), shows that the alongshore distribution in the landfast ice zone is "wavy" in the vicinity of the moored array (solid white line) and that there are extensive areas of open water or thin ice offshore of the landfast ice edge. This suggests that the surface stress distribution, which is related to both the surface winds and the sea-ice distribution function, has different scales of variability between the two time periods. This has important implications for the shelf response to wind-forcing, for while the alongshore wind field may be relatively uniform, variations in sea-ice distribution imply that the air-ice-ocean stress distribution may have substantial variability at smaller scales. One of the goals of this project is to understand how these variations are reflected in the along- and cross-shore flow fields.

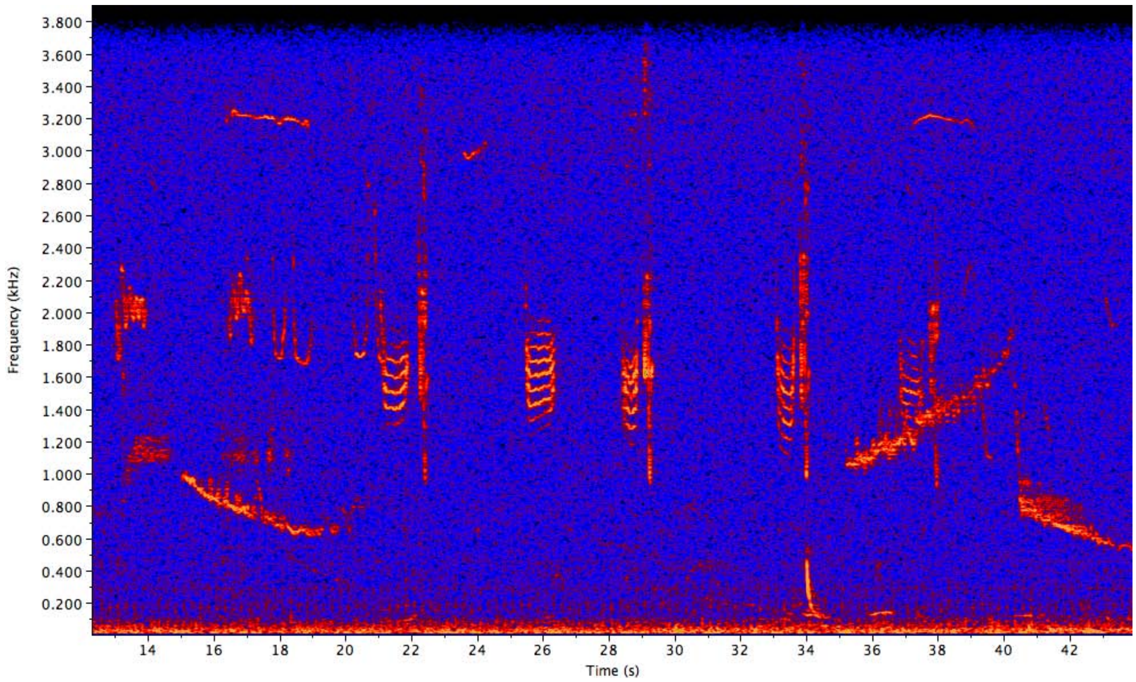

Figure 5. Beluga whale calls and bearded seal trills May 2009.

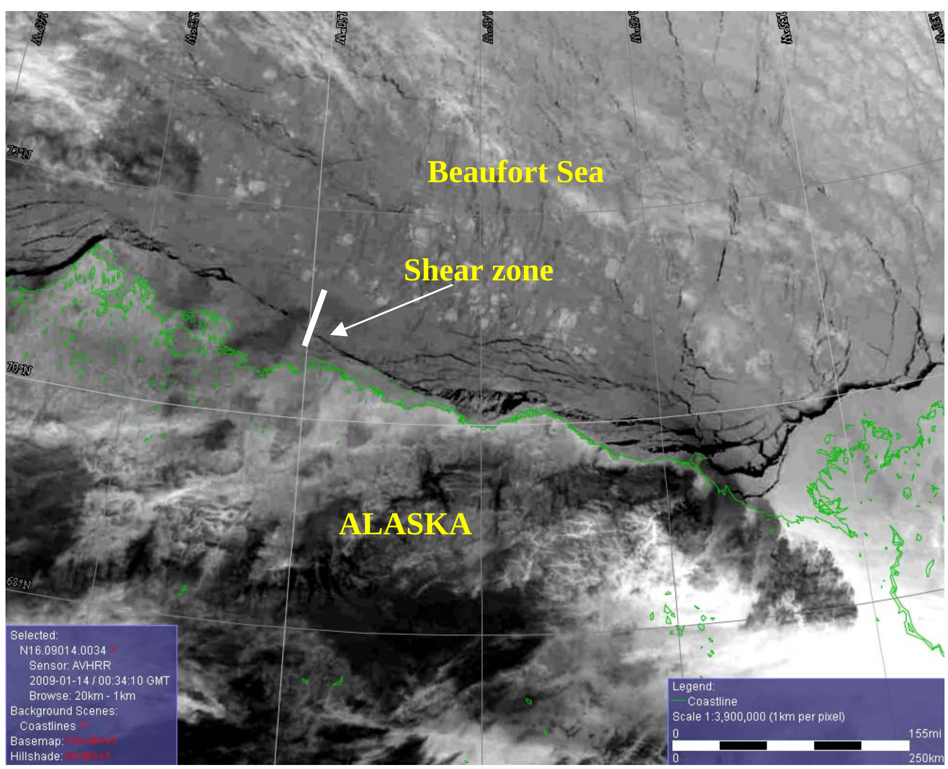

Figure 6. AVHRR imagery of the North Slope of Alaska and Beaufort Sea on January 14, 2009. The white line shows the approximate location of the NOPP mooring line in the central ABS.

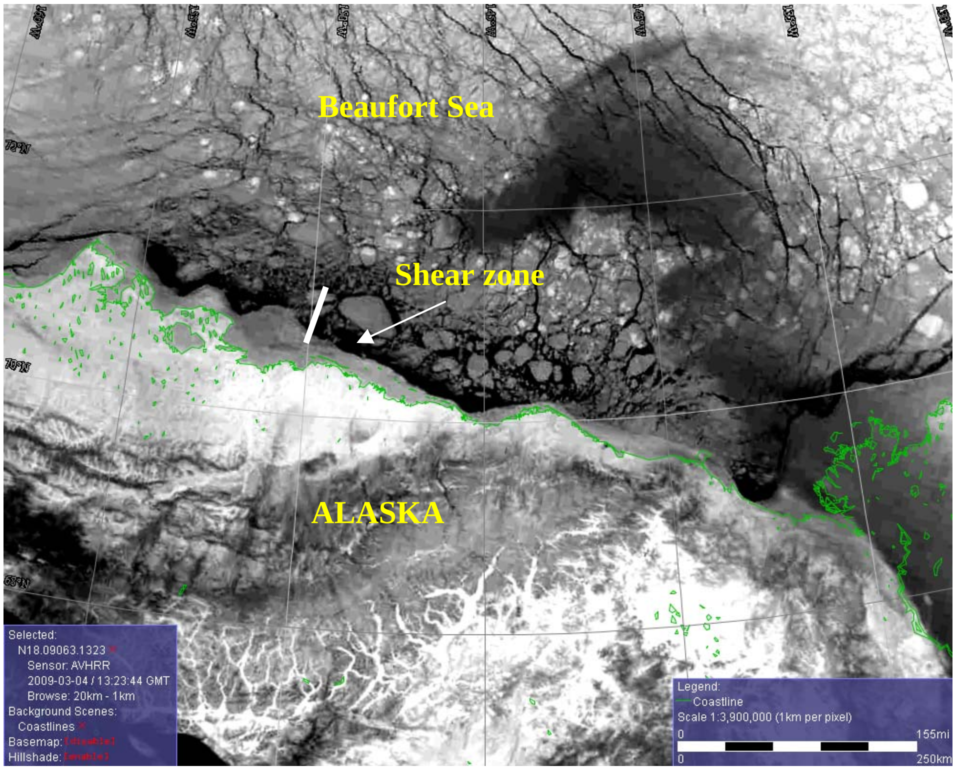

Figure 6. AVHRR imagery of the North Slope of Alaska and Beaufort Sea on March 4, 2009. The white line shows the approximate location of the NOPP mooring line in the central ABS.

IMPACT AND APPLICATIONS

National Security

Reduced ice cover has implications for National Security and Homeland Defense, including increased marine development and exploration, new shipping routes, and increased prominence of the USCG in the Arctic. This research will provide information useful for navigation, search and rescue, and minimizing potential hazards due to marine industrial development.

Economic Development

This project has indirect economic development influences on the offshore Alaskan oil industry and adjacent communities. This is reflected in the increased interest by industry in offshore exploration and development in offshore waters in northern Alaska. Our data will contribute to environmental and engineering designs. The economic importance of this effort is recognized by Shell Oil Inc., which has provided $184,000 additional funding to the project. We have alerted numerous industry and governmental entities about this project, and, in response, we have been informed of additional marine mammal recordings being made throughout the Beaufort and Chukchi seas. Ongoing discussions suggest that Drs. Moore and Stafford will be able synthesize many of these data sets to develop a more comprehensive understanding of marine mammal usage of these shelves. Figure 7 shows the distribution of recorders whose data are likely to be synthesized as a consequence of these collaborative efforts.

Quality of Life

This project represents the most systematic effort undertaken to understand the oceanography of the ABS and its year-round use by marine mammals. Physical measurements provide a basis for understanding the marine ecosystem and how best to address potential environmental changes. Marine mammals are of primary importance to the subsistence communities along the Beaufort Sea coast. Improved knowledge of marine mammal use of the shelf habitat will enhance management of these species by local communities and resource agencies.

Science Education and Communication

We anticipate several scientific papers will stem from this research. We will also prepare reports useful in developing oil spill response plans for the State of Alaska (see for example the report in http://www.ims.uaf.edu/beaufort/index3.html). We are starting work on project website similar to those developed for previous projects in which the PIs have been engaged. In addition we participated in the ONR Physical Oceanography Review in June 2009 and will be presenting aspects of our work at the Alaska Marine Science Symposium in January 2010. The latter meeting includes participants from industry, local community and municipal organizations, and state and federal government regulators. Since Shell Research and Exploration contributed funds to this project, Weingartner will travel to Houston in 2010 and present results of this project to Shell.

TRANSITIONS There are none at this time**.**

RELATED PROJECTS

This NOPP project will provide data for the evaluation of numerical models, headed by W. Maslowski of the Naval Post-graduate School, that seek to predict the response of the Alaskan coastal system to an ice-diminished Arctic. We have and will continue to collaborate via data sharing and logistics with Dr. Ashjian's project in the western Beaufort Sea. We will also share our oceanographic data with Dr. Cameron Wobus of the University of Colorado's Cooperative Institute for Research in Environmental Sciences. Dr. Wobus's NOPP project is looking at shoreline erosion in the western Beaufort Sea, and he has expressed interest in using our nearshore current measurements from the open water season in his project. His study site is indicated by the black circle in Figure 1.

As noted above, this NOPP project is establishing collaborations that will likely lead to a more comprehensive understanding of marine mammal utilization of these shelves. Dr. Weingartner is also a Co-PI on an MMS-funded project to assess marine fish distribution and abundances in the Alaskan Beaufort Sea. That project, led by Dr. Libby Logerwell of NOAA-NMFS's Alaska Fisheries Science Center's Status of Stocks and Multispecies Assessment (SSMA) Program, provided estimates of abundance, species composition, and biological information of marine fish and invertebrates, oceanographic properties, and information on the macro- and micro- zooplankton communities. The fish survey was conducted in mid-August 2008 and coincided with the shipboard efforts undertaken in this NOPP project in August 2008. These data, along with the August 2008 NOPP hydrographic data, resulted in nearly synoptic hydrographic coverage of the western half of the Beaufort Sea shelf.

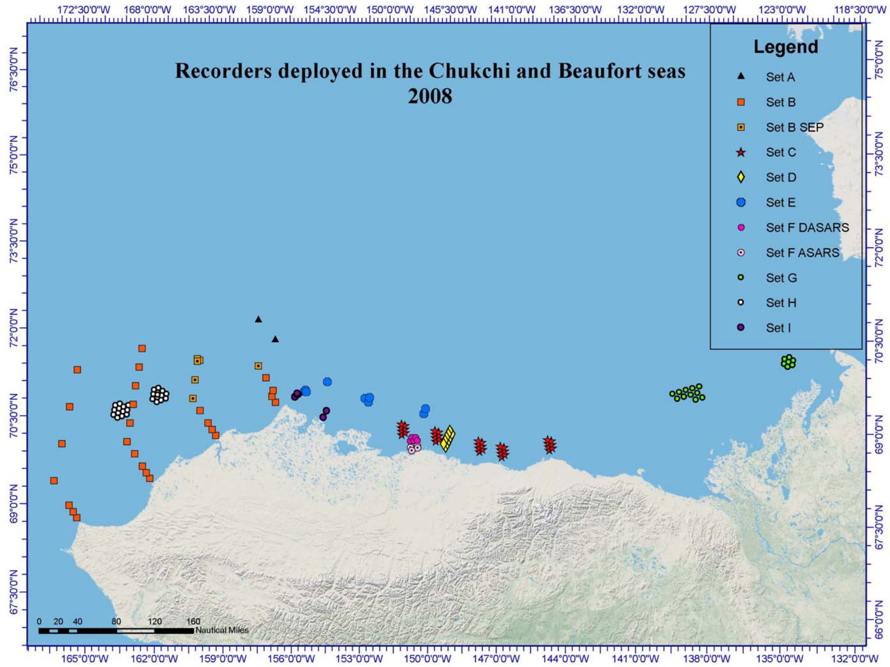

Figure 7. Distribution of marine mammal recorders in the Chukchi and Beaufort seas including those associated with the NOPP, the oil industry, and government agencies.